

Applicant(s)	McCallister	DECLARATION OF PROFESSOR NIHAR JINDAL Under 37 C.F.R §1.132
Serial No.	10/718,505	
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Group Art Unit	2611	
Examiner Name	Jean B Corrielus	
Confirmation No.	1245	
Attorney Docket No.	125.136USR1	
Title: CONSTRAINED-ENVELOPE TRANSMITTER AND METHOD THEREFOR		

I, Nihar Jindal, declare the following:

1. I have been retained by Intersil Americas, Inc, assignee of the above-captioned reissue patent application.
2. I am an Associate Professor in the Department of Electrical and Computer Engineering and the Digital Technology Center at the University of Minnesota, Twin Cities. I received the B.S degree in Electrical Engineering/Computer Science from the University of California, Berkeley in 1999 and the M.S. and PhD degrees in Electrical Engineering from Stanford University in 2001 and 2004.
3. I am an expert in wireless communication as demonstrated by the Curriculum Vitae (attached as Exhibit 1).
4. I have studied the paper May, et al, "Reducing the Peak-to-Average Power Ratio in OFDM Radio Transmission Systems," 48<sup>th</sup> IEEE Vehicular Technology Conference (1998) (hereinafter the May reference; copy attached as Exhibit 1). I have also studied the detailed description of the present application and the statements submitted by the inventor, Mr. McCallister, regarding the May reference.
5. It is my expert opinion that one of ordinary skill in the art would not be able to implement the system described in the May reference without undue experimentation. The primary deficiency in the May reference is its lack of detail regarding the timing of the various signals involved in the correction of the OFDM signal. As explained in more detail below, the silence of the May reference on this issue would require extensive experimentation for one of ordinary skill in the art to be able to reproduce May's results, if at all.
6. **The May Reference:**

A. In Section II.B of the May reference, it is stated that in [1] that Peak-to-Average Power Ratio (PAPR) is reduced by clipping the sampled signal, but that this approach does not provide any guarantees about the analog (continuous-time) waveform.

B. It is stated that in [5] the oversampled signal is clipped, and then filtered.

C. In describing [6], which is the reference that uses a multiplicative correction signal (as opposed to the additive correction signal), it is stated that “the OFDM signal is corrected by multiplying it with a correction function  $k(t)$ . If the signal exceeds the amplitude threshold  $A_0$  at the times  $t_n$ , then the corrected signal  $c(t)$  is”... Note that the set of possible values of  $t_n$  is not specified. A little further down in this description the following is stated: “Obviously, with this method it can be achieved to limit the amplitude of the oversampled signal...” This could possibly be interpreted as meaning that the technique of [6] is applied to the oversampled signal, although I do not believe this is clear.

D. Section III of the May reference describes the proposed additive correction function. After the equations for the corrected signal are given it is stated “This correction limits the signal  $s(t)$  to  $A_0$  at the positions  $t_n$  of amplitude peaks.” It is not specified whether or not the possible values of  $t_n$  are limited to some subset of time, or whether they can be arbitrary time instances. If the authors intend to imply that the values of  $t_n$  are free to be any time instance, then it must be noted that (i) no precise mathematical definition of the chosen  $t_n$  is given, i.e., there is no equation anywhere in the paper that specifies the  $t_n$  values, and (ii) not even an algorithmic description is provided of how to specify the  $t_n$  values.

E. It is my opinion that a person of ordinary skill would thus not know how to implement the proposed solution, as there are many different possible ways in which these time instants could be identified. For example, one could consider each excursion during which the waveform goes above the threshold (i.e., identify a contiguous time interval during which time  $s(t) \geq A_0$ ) and then identify the peak of this excursion. There are other alternatives, such as using the midpoint of each such excursion or using every time instance at which point  $s(t) > A_0$ . These different possibilities are stated simply to illustrate that there is great ambiguity in the critical issue of defining the  $t_n$  values.

F. A direct consequence of this ambiguity is the fact that no description is given of how, algorithmically, to identify the  $t_n$  values, and then to, algorithmically, appropriately delay the correction signal so that it is correctly and precisely synchronized with the uncorrected signal when the two signals are added together. Although both of these tasks are critical, the paper does not provide sufficient detail on either.

G. The May reference further states: “If the OFDM signal is not oversampled, then the sampled auxiliary function  $g(n * \text{delta\_t})$  is zero for all  $n$  not equal to zero. The correction scheme is identical with clipping in this case.” The May reference, at p. 2476, right hand column, lines 9-11. This sentence *might* be interpreted to imply that the performance of the proposed correction scheme somehow depends on whether or not the signal is oversampled, which in turn *might* lead one to believe that the correction should be applied to the sampled signal (whether or not it is oversampled). Some lines down, when the example is being described, it is stated “The signal  $s(t)$  has been oversampled by a factor of four”. *Id.* at lines 17-18. These things, when put together, might lead to believing that the correction is performed on the samples (i.e, the values of  $t_n$  is restricted to the instances at which the signal is sampled, which depends on the degree of oversampling). However, the above relations are certainly not explicit and they only represent one possible way of reading the message of May.

H. Furthermore, and very importantly, it is not explained how to implement the proposed correction function on the basis of the sampled signals. Are the values of  $t_n$  allowed to be any and all of the samples? In that case, the correction term could presumably be applied to every sample. If the oversampling factor was very large, then this would lead to a huge distortion of the signal and poor performance.

I. There is only one relevant working example in the May reference (bottom of pg. 2476), and it is very brief. It is my opinion that not nearly enough detail is provided in the May reference to recreate this example. Note that no flow chart or table is provided to explain the algorithm. It is not clear if the correction is applied to the samples or not. It is not clear what the signal waveforms have been used to generate Figures 3 and 4.

J. Finally, it is my opinion that undue experimentation would be needed for one of ordinary skill in the art to make or use the system described in the May reference. For example, one of ordinary skill in the art would need to determine how the time instants  $t_n$  should be defined. This would require a great deal of research, as there are a multitude of possibilities for this and it would not at all be clear to a person of ordinary skill how to go about selecting a candidate from these choices. It also would not be clear how to implement the required delaying of the correction waveform to guarantee it is synchronized with the uncorrected waveform.

K. **Summary:** It is my opinion that the May paper leaves many critical points unexplained: (1) how to define the  $t_n$  values, (2) how to find those  $t_n$  values, and (3) how to implement the required delays. These omissions add up to May not providing sufficient direction to enable one of ordinary skill in the art to practice the described technique. The May reference does not specify how the time/delay values  $t_n$  are to be selected, and there appear to be at least two different interpretations that a reader could extrapolate from the paper (neither is specified, so either approach has to be truly extrapolated). One possible interpretation is that  $t_n$

is allowed to take on any value. If this was the case, then it still is not clear how precisely the  $t_n$ 's are to be defined, since no equation or algorithm approach is described. Furthermore, the method to implementing the appropriate delaying of the correction waveform is not described. Another interpretation is to apply the correction algorithm to the samples of the signal. If this was the case, it still is not clear how to implement the authors' approach, since there are ambiguities regarding applying the approach to potentially all of the samples or just some of them. There is also the issue that if the oversampling rate is high, then this would result in very poor performance.

**7. McCallister statements:** The different written statements by McCallister repeatedly state that the May paper teaches that the values of  $t_n$  should correspond to the points at which the waveform  $s(t)$  achieves its maximum value above the threshold  $A_0$ , i.e., that the values of  $t_n$  should not be restricted to only sample points. (Note that this is the first of the two possible interpretations that I gleaned from the May paper). This is most clearly seen on pg. 7 of Mr. McCallister's Statement (dated Nov. 8, 2007):

May et al. used a different constraint than my co-inventors and I used: May et al. demanded very precise location of each signal peak,... May et. al modified the set of excursion samples by applying a simple gating on the excursion sample stream: only a single sample from any peak occurring within a set of contiguous excursion samples was permitted as input to the filter.

This text reveals two important things. First, McCallister believes that the May reference corresponds to a very specific implementation and choice of  $t_n$ , whereas my reading of the paper is that there are at least two very different possibilities for how the May solution could be implemented (see above). But if we agree that that is the correct interpretation of the May paper, McCallister's explanation – “only a single sample from any peak occurring within a set of contiguous excursion samples was permitted as input to the filter” – also illustrates that insufficient detail is provided in the May paper for this approach. This is because in the May reference, no detail is provided about how to pick the values of  $t_n$ , but from McCallister's statement we see that such detail clearly is required in order to actually implement May's algorithm.

**8. Overall summary:** Upon reading the May reference alone, the proposed algorithm could be extrapolated as applying to the precise time instants at which the signal achieves its maximum value or applying it to the samples of the signal. The text hints at both extrapolations, but sufficient detail is not provided for either. On the other hand, the McCallister declarations state that the May reference corresponds to applying the algorithm to the precise time instants (as opposed to only the samples) – it is not clear why McCallister has presumed that this is what the May reference implies – and then proceeds to “fill-in” the many details that are not provided in

the May reference. Furthermore, McCallister describes how applying correction to only some of the samples (those separated by a baud-interval) as specified in the patent at hand performs better than what he presumes is the May approach, and in doing so he also explains that the approach in the patent is quite different (in regard to identification of the values of the  $t_n$ 's) from what he presumes is the May approach. In summary, I agree completely with Neil Birch's comment that: "In my opinion a person of ordinary skill in the art could not implement May's system without undue experimentation."

9. **Fixed delay:** It is my opinion that the present application describes a fixed delay element; namely element 138 (see Fig. 2). First, it should be clarified that a "fixed delay element" is a single delay element in which the output waveform is equal to the input waveform delayed by a fixed amount of time, where the fixed amount of time is not dependent on the input to the delay element. In other words, the amount of delay is set to a particular value during the design of the system, and then is never changed or adapted. By this standard definition a delay element whose delay amount depends on the input waveform is not a fixed delay element; a delay element that delays different portions of the input waveform by different amounts of time is also not a fixed delay element.

A. The fact that 138 is a fixed delay element is clearly explained in column 11, lines 47-54, where it is stated:

Delay element 138 produces a delayed modulated signal 140, which is effectively modulated signal 74 delayed sufficiently to compensate for the propagation and other delays encountered in off-time constrained-envelope generator 106, and particularly in off-time pulse spreading filter 134. In other words, delayed modulated signal 140 is modulated signal 74 delayed into synchronism with off-time constrained-bandwidth error signal stream 108.

The first sentence in the above passage makes it clear that delay element 138 delays its input, modulated signal 74, by the sum of the propagation delay and the delay imposed by the pulse-spreading filter 134 within the off-time constrained-envelope generator and any other delay encountered in off-time constrained generator 106. Those skilled in the art would see that the "propagation delay" clearly refers to the physical time taken to pass the signal from 77 to 106, which is a physically measurable quantity that clearly only depends on the actual implementation of the circuit and not on the input waveform. It is also clear to those skilled in the art that the delay imposed by the pulse-spreading filter 134 is a constant, input-independent quantity. In fact, in column 11, lines 33-36, it is stated that off-time pulse spreading filter 134 is "essentially the same as the operation of pulse-spreading filter 76 in the conversion of phase-point signal stream 50 into modulated signal 74 described hereinabove", and the operation of 76 is described in column 7, lines 37-40: "Of course, those skilled in the art will appreciate that signal streams

74 and 84 may be delayed from signal stream 50 by a delay imposed by filter 76." This passage refers to the standard delay that is imposed by the implementation of a filter, as appreciated by those skilled in the art. Finally, the "any other delay encountered" phrase in the passage quoted earlier would be interpreted by those skilled in the art as simply allowing for the possibility of other delays in 106, such as time to perform the combining and discriminating activities. Thus, the three components of the delay in delay element 138 are each input-independent. As a result, delay element 138 imposes a constant, i.e., fixed, delay, regardless of what the value of its input (74) is. Thus, this attests to the fact that 138 is a fixed delay element.

10. I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Dated: \_\_\_\_\_ October 5, 2010 \_\_\_\_\_

By: \_\_\_\_\_/Nihar Jindal/ \_\_\_\_\_

Nihar Jindal

# Nihar Jindal

Dept of Electrical and Computer Engr, Room 6-119  
University of Minnesota  
200 Union Street SE  
Minneapolis, MN 55455

Phone: (612) 625-6306  
Email: [nihar@umn.edu](mailto:nihar@umn.edu)  
Web: <http://www.ece.umn.edu/users/nihar>

**Education**      **Stanford University**      *1999-2004*  
PHD. ELECTRICAL ENGINEERING, July 2004  
M.S. ELECTRICAL ENGINEERING, June 2001  
*Thesis:* Multi-User Communication Channels: Capacity, Duality, and Cooperation  
*Advisor:* Prof. Andrea Goldsmith  
*Associate Advisor:* Prof. Thomas Cover

**University of California, Berkeley**      *1995-1999*  
B.S. ELECTRICAL ENGINEERING/COMPUTER SCIENCE, May 1999

## Work Experience

**University of Minnesota**, Minneapolis, MN      *Sept. 2010 - Present*  
*Associate Professor*

**University of Minnesota**, Minneapolis, MN      *Aug. 2004 - Aug. 2010*  
*Assistant Professor*

### Research

- Wireless communication
- Multi-user/multi-antenna communication systems
- Ad-hoc networks
- Cross-layer design of communication networks
- Dynamic resource allocation for fading channels
- Multi-user information theory

### Teaching

- Wireless Communication (EE 5505), Spring 2010, Spring 2007, Spring 2006
- Information Theory and Coding (EE 5581), Fall 2010, Fall 2007, Fall 2005
- Digital Communication (EE 5501), Fall 2009
- Advanced Topics in Wireless Communication (EE 8950), Spring 2008
- Statistical Methods in Electrical and Computer Engineering (EE 3025), Fall 2006
- Multi-User Information Theory (EE 8510), Spring 2005
- Participant in Early Career Faculty Teaching Program, 2005-2006

**Bell Labs, Lucent Technologies**, Crawford Hill, NJ      *June - August 2002*  
*Summer Intern, Wireless Research Lab*  
Mentor: Dr. Gerald Foschini

- Analyzed performance of pre-coding techniques for multiple-antenna downlink cellular systems.
- Evaluated potential gain due to multiple base station cooperation in a cellular environment.

**Intel Corporation**, Santa Clara, CA  
*Summer Intern, Microprocessor Research Lab*  
Mentor: Dr. Leslie Rusch

*June - Sept 2000*

- Evaluated performance of advanced signal processing techniques in wireless LAN receivers.

#### **Honors**

- Guillermo E. Borja Award, University of Minnesota, 2010
- NSF CAREER Award, 2008.
- McKnight Land-Grant Professor, University of Minnesota, 2007-2009
- Ezra Frederick Scattergood Fellowship, Stanford University
- Electrical Engineering Honors Program, UC-Berkeley
- Member Eta Kappa Nu

#### **Paper Awards**

- IEEE Communications Society Leonard G. Abraham Prize (JSAC Best Paper Award) 2009, "Limited Feedback-Based Block Diagonalization for the MIMO Broadcast Channel"
- IEEE Communications Society and Information Theory Society Joint Paper Award 2005, "On the Duality of Gaussian Multiple-Access and Broadcast Channels"

#### **Professional Affiliations**

- IEEE Information Theory Society
- IEEE Communications Society

#### **Professional Service**

- Associate Editor, IEEE Transactions on Communications, 2007-Present
- Treasurer, IEEE Information Theory Society, 2010-12
- Technical Program Co-Chair, IEEE Communication Theory Workshop, 2010
- Guest Editor, EURASIP Journal on Advances in Signal Processing, Special Issue on "Multiuser MIMO Transmission with Limited Feedback, Cooperation, and Coordination," 2008
- Guest Editor, EURASIP Journal on Wireless Communications and Networking, Special Issue on "Theory and Applications in Multiuser/Multiterminal Communications," 2008
- Treasurer, IEEE Communication Theory Workshop 2009; Poster Co-Chair, IEEE Communication Theory Workshop 2008.
- Technical Program Co-Chair, Multiple Antennas and Space-Time Processing Track, IEEE Vehicular Technology Conference, Fall 2007
- Technical Program Committee Member: IEEE Int. Symp. on Information Theory (ISIT) 2007, 2008, 2009, IEEE Int. Conf. of Communications (ICC) 2006, 2008, 2009, IEEE Global Telecommunications Conf.(Globecom) 2006, 2007, 2008, 2009, WiOpt 2008, Information Processing in Sensor Networks (IPSN) 2006, RAWNET 2006, Int. Wireless Commun. and Mobile Comput. Conf. (IWCMC) 2006, IEEE WirelessComm 2005, IEEE VTC 2005
- Reviewer for IEEE Transactions on Information Theory, IEEE Transactions on Communications, IEEE Communications Letters, IEEE Transactions on Wireless Communications, IEEE Journal on Selected Areas in Communications, IEEE Transactions on Signal Processing.
- President, IEEE Twin Cities Chapter of Signal Processing and Communication Societies, 2005 - Present

## Journal Publications

1. Peng Wu and Nihar Jindal, "Coding versus ARQ in Fading Channels: How Reliable should the PHY be?", Submitted: *IEEE Transactions on Communications*, March 2010.
2. Nihar Jindal, Jeff Andrews, and Steven Weber, "Multi-Antenna Communication in Ad Hoc Networks: Achieving MIMO Gains with SIMO Transmission", Submitted: *IEEE Transactions on Communications*, Dec. 2009.
3. Mari Kobayashi, Nihar Jindal, and Giuseppe Caire, "Training and Feedback Optimization for Multiuser MIMO Downlink", Submitted: *IEEE Transactions on Communications*, Dec. 2009.
4. Juyul Lee and Nihar Jindal, "Asymptotically Optimal Policies for Hard-deadline Scheduling over Fading Channels," Submitted: *IEEE Transactions on Information Theory*, June 2009.
5. Steven Weber, Jeff Andrews, and Nihar Jindal, "An Overview of the Transmission Capacity of Wireless Networks," To Appear: *IEEE Transactions on Communications*, 2010.
6. Nihar Jindal and Angel Lozano, "A Unified Treatment of Optimum Pilot Overhead in Multipath Fading Channels," To Appear: *IEEE Transactions on Communications*, 2010.
7. Giuseppe Caire, Nihar Jindal, Mari Kobayashi, and Niranjay Ravindran, "Multiuser MIMO Achievable Rates with Downlink Training and Channel State Feedback," To Appear: *IEEE Transactions on Information Theory*, 2010.
8. Peng Wu and Nihar Jindal, "Performance of Hybrid-ARQ in Block-Fading Channels: A Fixed Outage Probability Analysis," *IEEE Transactions on Communications*, Vol. 58, No. 4, pp. 1129-1141, April 2010.
9. Angel Lozano and Nihar Jindal, "Transmit Diversity v. Spatial Multiplexing in Modern MIMO Systems," *IEEE Transactions on Wireless Communications*, Vol. 9, No. 1, pp. 186-197, Jan. 2010.
10. Juyul Lee and Nihar Jindal, "Energy-efficient Scheduling of Delay Constrained Traffic over Fading Channels," *IEEE Transactions on Wireless Communications*, Vol. 8, No. 4, pp. 1866-1875, April 2009.
11. J. Andrews, N. Jindal, M. Haenggi, R. Berry, S. Jafar, D. Guo, S. Shakkottai, R. Heath, M. Neely, S. Weber, and A. Yener, "Rethinking Information Theory for Mobile Ad Hoc Networks," *IEEE Communications Magazine*, Vol. 46, No. 12, pp. 94-101, Dec. 2008.
12. Nihar Jindal, Jeff Andrews, and Steven Weber, "Bandwidth Partitioning in Decentralized Wireless Networks," *IEEE Transactions on Wireless Communications*, Vol. 7, No. 12, pp. 5408-5419, Dec. 2008.
13. Nihar Jindal, Steven Weber, and Jeff Andrews, "Fractional Power Control for Decentralized Wireless Networks," *IEEE Transactions on Wireless Communications*, Vol. 7, No. 12, pp. 5482-5492, Dec. 2008.
14. Chan-Byoung Chae, David Mazzarese, Nihar Jindal and Robert W. Heath, Jr., "Coordinated Beamforming with Limited Feedback in the MIMO Broadcast Channel", *IEEE Journal on Selected Areas in Communications*, Vol. 26, No. 8, pp. 1505-1515, Oct. 2008.
15. Niranjay Ravindran and Nihar Jindal, "Limited Feedback-Based Block Diagonalization for the MIMO Broadcast Channel," *IEEE Journal on Selected Areas in Communications*, Vol. 26, No. 8, pp. 1473-1482, Oct. 2008. **(Recipient of 2009 IEEE Leonard G. Abraham Prize - JSAC Best Paper Award)**
16. Nihar Jindal, "Antenna Combining for the MIMO Downlink Channel", *IEEE Transactions on Wireless Communications*, Vol. 7, No. 10, pp. 3834-3844, Oct. 2008.

17. Ioannis Schizas, Georgios Giannakis and Nihar Jindal, "Distortion-Rate Bounds for Distributed Estimation with Wireless Sensor Networks," *EURASIP Journal on Advances in Signal Processing*, Special Issue on Distributed Signal Processing Techniques for Wireless Sensor Networks, 2008.
18. Juyul Lee and Nihar Jindal, "High SNR Analysis for MIMO Broadcast Channels: Dirty Paper Coding vs. Linear Precoding," *IEEE Transactions on Information Theory*, Vol. 53, No. 12, pp. 4787-4792, Dec. 2007.
19. Steven Weber, Jeff Andrews, and Nihar Jindal, "The Effect of Fading, Channel Inversion, and Threshold Scheduling on Ad Hoc Networks," *IEEE Transactions on Information Theory*, Vol. 53, No. 11, pp. 4127-4149, Nov. 2007.
20. Chris Ng, Nihar Jindal, Andrea Goldsmith, and Urbashi Mitra, "Capacity Gain from Two-Transmitter and Two-Receiver Cooperation," *IEEE Transactions on Information Theory*, Vol. 53, No. 10, pp. 3822-3827, Oct. 2007.
21. Taesang Yoo, Nihar Jindal, and Andrea Goldsmith, "Multi-Antenna Downlink Channels with Limited Feedback and User Selection," *IEEE Journal on Selected Areas in Communications*, Vol. 25, No. 7, pp. 1478-1491, Sept. 2007. (Nominated for JSAC Best Paper Award).
22. Yingqun Yu, Georgios Giannakis, and Nihar Jindal, "Information-Bearing Noncoherently Modulated Pilots for MIMO Training," *IEEE Transactions on Information Theory*, Vol. 53, No. 3, pp. 1160-1167, March 2007.
23. Nihar Jindal, "MIMO Broadcast Channels with Finite-Rate Feedback," *IEEE Transactions on Information Theory*, Vol. 52, No. 11, pp. 5045-5059, Nov. 2006.
24. Nihar Jindal and Andrea Goldsmith, "Dirty-Paper Coding vs. TDMA for MIMO Broadcast Channels", *IEEE Transactions on Information Theory*, Vol. 51, No. 5, pp. 1783-1794, May 2005.
25. Nihar Jindal, Wonjong Rhee, Sriram Vishwanath, Syed Ali Jafar, and Andrea Goldsmith, "Sum Power Iterative Water-filling for Multi-Antenna Gaussian Broadcast Channels," *IEEE Transactions on Information Theory*, Vol. 51, No. 4, pp. 1570-1580, April 2005.
26. Lifang Li, Nihar Jindal, and Andrea Goldsmith, "Outage Capacities and Optimal Power Allocation for Fading Multiple-Access Channels," *IEEE Transactions on Information Theory*, Vol. 51, No. 4, pp. 1326-1347, April 2005.
27. Nihar Jindal, Sriram Vishwanath, and Andrea Goldsmith, "On the Duality of Gaussian Multiple-Access and Broadcast Channels," *IEEE Transactions on Information Theory*, Vol. 50, No. 5, pp. 768-783, May 2004. **(Recipient of 2005 IEEE ComSoc/IT Society Joint Paper Award)**
28. Nihar Jindal and Andrea Goldsmith, "Capacity and Optimal Power Allocation for Fading Broadcast Channels with Minimum Rates," *IEEE Transactions on Information Theory*, Vol. 49, No. 11, pp. 2895-2909, Nov. 2003.
29. Sriram Vishwanath, Nihar Jindal, and Andrea Goldsmith, "Duality, Achievable Rates, and Sum-Rate Capacity of Gaussian MIMO Broadcast Channels," *IEEE Transactions on Information Theory*, Vol. 49, No. 10, pp. 2658-2668, Oct. 2003.
30. Andrea Goldsmith, Syed Ali Jafar, Nihar Jindal, and Sriram Vishwanath, "Capacity Limits of MIMO Channels," *IEEE Journal on Selected Areas in Communications*, Vol. 21, No. 5, pp. 684 -702, June 2003.

## Conference Publications

1. Joseph Blomer and Nihar Jindal, "Opportunistic Routing in Ad Hoc Networks: How many relays should there be? What rate should nodes use?" *IEEE Global Communications Conference*, Dec. 2010.
2. Fredrik Rusek, Angel Lozano, and Nihar Jindal, "Mutual Information of IID Complex Gaussian Signals on Block Rayleigh-faded Channels" *IEEE International Symposium on Information Theory*, June 2010.
3. Peng Wu and Nihar Jindal, "Coding versus ARQ in Fading Channels: How Reliable should the PHY be?" *IEEE Global Communications Conference*, Nov. 2009.
4. Nihar Jindal and Angel Lozano, "De-hyping Transmit Diversity in Modern MIMO Cellular Systems" *IEEE Global Communications Conference*, Nov. 2009.
5. Juyul Lee and Nihar Jindal, "Asymptotically Optimal Policies for Hard-deadline Scheduling over Fading Channels," *Allerton Conference on Communication, Control, and Computing*, Oct. 2009.
6. Nihar Jindal, Angel Lozano, and Thomas Marzetta, "What is the Value of Joint Processing of Pilots and Data in Block-Fading Channels?" *IEEE International Symposium on Information Theory*, July 2009.
7. Nihar Jindal, Jeff Andrews, and Steven Weber, "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas," *IEEE International Conference on Communications*, June 2009.
8. Juyul Lee and Nihar Jindal, "Delay Constrained Scheduling over Fading Channels: Optimal Policies for Monomial Energy-Cost Functions," *IEEE International Conference on Communications*, June 2009.
9. Joseph Blomer and Nihar Jindal, "Transmission Capacity of Wireless Ad Hoc Networks: Successive Interference Cancellation vs. Joint Detection," *IEEE International Conference on Communications*, June 2009.
10. Mari Kobayashi, Nihar Jindal, and Giuseppe Caire "Optimized Training and Feedback for MIMO Downlink Channels," *IEEE Information Theory Workshop*, June 2009. (Invited Paper)
11. Mariam Kaynia, Gier Oien, and Nihar Jindal, "Impact of Fading on the Performance of ALOHA and CSMA," *IEEE Workshop on Signal Processing Advances in Wireless Communications*, June 2009.
12. Steven Weber, Nihar Jindal, Radha Krishna Ganti, and Martin Haenggi, "Longest Edge Routing on the Spatial Aloha Graph," *IEEE Global Communications Conference*, Nov. 2008.
13. Mariam Kaynia, Gier Oien, Nihar Jindal, and David Gesbert, "Comparative Performance Evaluation of MAC Protocols in Ad Hoc Networks with Bandwidth Partitioning," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Sept. 2008.
14. Mari Kobayashi, Giuseppe Caire, and Nihar Jindal, "How Much Training and Feedback are Required in MIMO Broadcast Channels?" *IEEE International Symposium on Information Theory*, July 2008.
15. Juyul Lee and Nihar Jindal, "Energy-efficient Scheduling of Delay Constrained Traffic over Fading Channels," *IEEE International Symposium on Information Theory*, July 2008.
16. Niranjay Ravindran and Nihar Jindal, "Multi-User Diversity vs. Accurate Channel Feedback for MIMO Broadcast Channels," *IEEE International Conference on Communications*, May 2008.
17. Peng Wu and Nihar Jindal, "Analysis of Fixed Outage Transmission Schemes: A Finer Look at the Full Multiplexing Point," *IEEE International Conference on Communications*, May 2008.

18. Mariam Kaynia and Nihar Jindal, "Performance of ALOHA and CSMA in Spatially Distributed Wireless Networks," *IEEE International Conference on Communications*, May 2008.
19. Chris Ng, Nihar Jindal, Andrea Goldsmith, and Urbashi Mitra, "Power and Bandwidth Allocation in Cooperative Dirty Paper Coding," *IEEE International Conference on Communications*, May 2008.
20. Chan-Byoung Chae, David Mazzarese, Nihar Jindal, and Robert W. Heath, "A Low Complexity Linear Multiuser MIMO Beamforming System with Limited Feedback," *Conference on Information Sciences and Systems*, March 2008.
21. Niranjay Ravindran, Nihar Jindal, and Howard Huang, "Beamforming with Finite Rate Feedback for LOS MIMO Downlink Channels", *IEEE Global Communications Conference*, November 2007.
22. Giuseppe Caire, Nihar Jindal, and Shlomo Shamai, "On the Required Accuracy of Transmitter Channel State Information in Multiple Antenna Broadcast Channels", *Asilomar Conference on Signals, Systems, and Computers*, Oct. 2007. (Invited Paper)
23. Nihar Jindal, Jeff Andrews, and Steven Weber, "Energy-Limited vs. Interference-Limited Ad Hoc Network Capacity," *Asilomar Conference on Signals, Systems, and Computers*, Oct. 2007. (Invited Paper)
24. Nihar Jindal, Steven Weber, and Jeff Andrews, "Fractional Power Control for Decentralized Wireless Networks", *Allerton Conference on Communication, Control, and Computing*, Sept. 2007.
25. Giuseppe Caire, Nihar Jindal, Mari Kobayashi, and Niranjay Ravindran, "Achievable Throughput of MIMO Downlink Beamforming with Limited Channel Information," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Aug. 2007. (Invited Paper)
26. Nihar Jindal, Jeff Andrews, and Steven Weber, "Bandwidth-SINR Tradeoffs in Spatial Networks", *IEEE International Symposium on Information Theory*, June 2007.
27. Giuseppe Caire, Nihar Jindal, Mari Kobayashi, and Niranjay Ravindran, "Quantized vs. Analog Feedback for the MIMO Broadcast Channel: A Comparison between Zero-Forcing Based Achievable Rates", *IEEE International Symposium on Information Theory*, June 2007.
28. Niranjay Ravindran and Nihar Jindal, "MIMO Broadcast Channels with Block Diagonalization and Finite Rate Feedback", *IEEE International Conference on Acoustics, Speech, and Signal Processing*, April 2007.
29. Nihar Jindal, Jeff Andrews, and Steven Weber, "Optimizing the SINR Operating Point of Spatial Networks", *Workshop on Information Theory and its Applications*, Jan. 2007. (Invited Paper)
30. Jin-Jun Xiao, Zhi-Quan (Tom) Luo, and Nihar Jindal, "Linear Joint Source-Channel Coding for Gaussian Sources through Fading Channels", *IEEE Global Communications Conference*, San Francisco, CA, Nov. 2006.
31. Giuseppe Caire, Nihar Jindal, and Mari Kobayashi, "Achievable Rates of MIMO Downlink Beamforming with Non-Perfect CSI: A Comparison Between Quantized and Analog Feedback", *Asilomar Conference on Signals, Systems, and Computers*, Oct. 2006. (Invited Paper)
32. Juyul Lee and Nihar Jindal, "Dirty Paper Coding vs. Linear Precoding for MIMO Broadcast Channels", *Asilomar Conference on Signals, Systems, and Computers*, Oct. 2006. (Invited Paper)
33. Nihar Jindal, "MIMO Broadcast Channels with Digital Channel Feedback", *Asilomar Conference on Signals, Systems, and Computers*, Oct. 2006. (Invited Paper)
34. Steven Weber, Jeff Andrews, and Nihar Jindal, "Throughput and Transmission Capacity of Ad Hoc Networks with Channel State Information", *Allerton Conference on Communication, Control, and Computing*, Sept. 2006.

35. Juyul Lee and Nihar Jindal, "Symmetric Capacity of MIMO Broadcast Channels", *IEEE International Symposium on Information Theory*, July 2006.
36. Nihar Jindal, "A Feedback Reduction Technique for MIMO Broadcast Channels", *IEEE International Symposium on Information Theory*, July 2006.
37. Nihar Jindal and Zhi Quan (Tom) Luo, "Capacity Limits of Multiple Antenna Multicast", *IEEE International Symposium on Information Theory*, July 2006.
38. Taesang Yoo, Nihar Jindal, and Andrea Goldsmith, "Finite-Rate Feedback MIMO Broadcast Channels with a Large Number of Users", *IEEE International Symposium on Information Theory*, July 2006.
39. Sudhir Srinivasa, Syed Ali Jafar, and Nihar Jindal, "On the Capacity of the Cognitive Tracking Channel", *IEEE International Symposium on Information Theory*, July 2006.
40. Nihar Jindal, "Finite Rate Feedback MIMO Broadcast Channels", *Workshop on Information Theory and its Applications*, Feb. 2006. (Invited Paper)
41. Nihar Jindal, "MIMO Broadcast Channels with Finite Rate Feedback", *IEEE Global Communications Conference*, Oct. 2005.
42. Ioannis Schizas, Georgios Giannakis, and Nihar Jindal, "Distortion-Rate Analysis for Distributed Estimation with Wireless Sensor Networks," *Allerton Conference on Communication, Control, and Computing*, Sept. 2005.
43. Nihar Jindal, "High SNR Analysis of MIMO Broadcast Channels", *IEEE International Symposium on Information Theory*, Sept. 2005.
44. Nihar Jindal and Andrea Goldsmith, "Capacity and Dirty Paper Coding for Gaussian Broadcast Channels with Common Information," *IEEE International Symposium on Information Theory*, June 2004.
45. Nihar Jindal, Urbashi Mitra, and Andrea Goldsmith, "Capacity of Ad-Hoc Networks with Node Cooperation," *IEEE International Symposium on Information Theory*, June 2004.
46. Nihar Jindal and Andrea Goldsmith, "Dirty Paper Coding vs. TDMA for MIMO Broadcast Channels," *IEEE International Conference on Communications*, June 2004.
47. Sriram Vishwanath, Nihar Jindal, and Andrea Goldsmith, "The "Z" channel," *IEEE Global Communications Conference*, Dec. 2003.
48. Sriram Vishwanath, Wonjong Rhee, Nihar Jindal, Syed Ali Jafar, and Andrea Goldsmith, "Sum Power Iterative Water-filling for Gaussian Vector Broadcast Channels," *IEEE International Symposium on Information Theory*, July 2003.
49. Nihar Jindal, Sriram Vishwanath, and Andrea Goldsmith, "On the Duality Between General Multiple-Access/Broadcast Channels," *IEEE International Symposium on Information Theory*, July 2003.
50. Nihar Jindal, Syed Ali Jafar, Sriram Vishwanath, and Andrea Goldsmith, "Sum Power Iterative Water-filling for Multi-Antenna Gaussian Broadcast Channels," *Asilomar Conference on Signals, Systems, and Computers*, Nov. 2002.
51. Nihar Jindal, Sriram Vishwanath, Syed Ali Jafar, and Andrea Goldsmith, "Duality, Dirty Paper Coding, and Capacity for Multiuser Wireless Channels," *DIMACS Workshop on Signal Processing for Wireless Transmission*, Oct. 2002. (Invited Paper)
52. Raymond Wang, Nihar Jindal, Thomas Bruns, Ahmed Bahai, and Donald C. Cox, "Comparing RLS and LMS Adaptive Equalizers for Nonstationary Wireless Channels in Mobile Ad Hoc Networks," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Sept. 2002.
53. Nihar Jindal, Sriram Vishwanath, and Andrea Goldsmith, "On the Duality of Gaussian Multiple-Access and Broadcast Channels," *IEEE International Symposium on Information Theory*, July 2002.

54. Sriram Vishwanath, Nihar Jindal, and Andrea Goldsmith, "On the Capacity of Multiple Input Multiple Output Broadcast Channels," *IEEE International Conference on Communications*, April 2002.
55. Nihar Jindal and Andrea Goldsmith, "Capacity and Optimal Power Allocation for Fading Broadcast Channels with Minimum Rates," *IEEE Global Communications Conference*, Nov. 2001.
56. Nihar Jindal, Sriram Vishwanath, and Andrea Goldsmith, "On the Duality of Multiple-Access and Broadcast Channels," *Allerton Conference on Communication, Control, and Computing*, Oct. 2001.

## Book Chapters

1. Andrea Goldsmith, Syed Ali Jafar, Nihar Jindal, and Sriram Vishwanath, Chapter Title: "Capacity Limits of MIMO Systems", Book Title: "MIMO Wireless Communications", Cambridge University Press, 2007.

## Tutorials

1. Andrea Goldsmith, Syed Ali Jafar, Nihar Jindal, and Sriram Vishwanath, "Capacity Limits of MIMO Systems", IEEE Global Communications Conference 2005, St. Louis, MO.
2. Andrea Goldsmith, Syed Ali Jafar, Nihar Jindal, and Sriram Vishwanath, "Capacity Limits of MIMO Systems", IEEE International Symposium on Information Theory, 2005, Adelaide, Australia.
3. Ali Ghayeb, Georgios Giannakis, Andrea Goldsmith, Syed Ali Jafar, Nihar Jindal, Reinaldo Valenzuela, Sriram Vishwanath, and Shengli Zhou, "Theory and Practice of MIMO: Promises and Realities", IEEE Global Communications Conference 2004, Dallas, TX.

## Invited Presentations

1. DoCoMo Labs, "A System-Level Perspective on CSI for Space-Division Multiple Access", Palo Alto, CA, June 2010.
2. Qualcomm Inc., "A System-Level Perspective on CSI for Space-Division Multiple Access", San Diego, CA, Jan. 2010.
3. Yonsei University, Distinguished Seminar Series, "Delay Constrained Scheduling over Fading Channels", Seoul, Korea, July. 2009.
4. University of Athens, "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas", Athens, Greece, June 2009.
5. Washington State Community College Math Conference, "Mathematics of Wireless Communication", Pasco, Washington, April 2009. (Keynote Speaker)
6. Indian Institute of Technology (IIT), "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas", Chennai, India, Dec. 2008.
7. Indian Institute of Science, "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas", Bangalore, India, Dec. 2008.
8. Universitat Politècnica de Catalunya, "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas", Barcelona, Spain, Nov. 2008.
9. CTTC, "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas", Barcelona, Spain, Nov. 2008.

10. EURECOM, "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas", Sophia-Antipolis, France, Nov. 2008.
11. Supelec, "Rethinking MIMO for Wireless Networks: Linear Throughput Increases with Multiple Receive Antennas", Paris, France, Nov. 2008.
12. Universidad Carlos III, "Performance of Hybrid-ARQ in Block-Fading: A Fixed Outage Analysis", Madrid, Spain, Oct. 2008.
13. Universidad Rey Juan Carlos, "Performance of Hybrid-ARQ in Block-Fading: A Fixed Outage Analysis", Madrid, Spain, Oct. 2008.
14. IEEE Communication Theory Workshop, "Channel Feedback for Multiuser MIMO Downlink Channels", US Virgin Islands, May 2008.
15. Technical University-Berlin, "Performance of Hybrid ARQ in Fixed Outage Settings," Berlin, Germany, April 2008.
16. Northwestern University, "Multiuser MIMO Downlink Made Practical: Achievable Rates with Simple Channel State Estimation and Feedback Schemes," Evanston, IL, April 2008.
17. University of Colorado, Boulder, "Multi-User Diversity vs. Channel Feedback: Is Accurate Channel Feedback from a Few Users Preferable to Coarse Feedback from Many Users?" Feb. 2008.
18. University of California, Berkeley, "Bandwidth Partitioning in Decentralized Wireless Networks," Berkeley, CA, Oct. 2007.
19. Princeton University, "Achievable Throughput of MIMO Downlink Beamforming with Limited Channel Information", Princeton, NJ, Oct. 2007.
20. Penn State University, "Achievable Throughput of MIMO Downlink Beamforming with Limited Channel Information", College Station, PA, Oct. 2007.
21. Seoul National University, "MIMO Downlink Channels with Imperfect Channel Information", Seoul, Korea, Aug. 2007.
22. Yonsei University, "MIMO Downlink Channels with Imperfect Channel Information", Seoul, Korea, Aug. 2007.
23. University of California, Los Angeles, "Optimizing Frequency Reuse in Ad-Hoc Networks", Los Angeles, CA, May 2007.
24. University of Southern California, "Optimizing Frequency Reuse in Ad-Hoc Networks", Los Angeles, CA, May 2007.
25. Workshop on Resource Allocation in Wireless Networks (associated with WiOpt), "Multiple Antenna Downlink Channels: From Theory to Practice", Limassol, Cyprus, April 2007. (Keynote Speaker)
26. Purdue University, "MIMO Downlink Channels: From Theory to Practice", West Lafayette, IA, March. 2007.
27. Rice University, "Optimizing Frequency Reuse in Ad-Hoc Networks", Houston, TX, Feb. 2007.
28. Hughes Network Systems, "Multi-User MIMO: The Next Frontier in Wireless Networks", Germantown, MD, Sept. 2006.
29. Bell Labs, "Finite Rate Feedback MIMO Downlink Channels", Crawford Hill, NJ, May 2006.
30. Bell Labs, "Finite Rate Feedback MIMO Downlink Channels", Murray Hill, NJ, May 2006.
31. Motorola Research Labs, "Multi-User MIMO: The Next Frontier in Wireless Networks", Schaumburg, IL, Feb. 2006.
32. Ohio State University, Information Processing Systems Laboratory Seminar Series, "MIMO Broadcast Channels with Finite Rate Feedback", Jan. 2006

33. Melbourne Information Theory Workshop, "MIMO Broadcast Channels with Finite Rate Feedback", Melbourne, Australia, Aug. 2005.
34. Swiss Federal Institute of Technology (ETH), "MIMO Broadcast Channels at High SNR", Zurich, Switzerland, May 2005.
35. Telecommunications Research Center Vienna (ftw), "MIMO Broadcast Channels with Finite Rate Feedback", Vienna, Austria, May 2005.
36. Adventium Labs, "Multiple Antenna Communication", Minneapolis, MN, February 2005.
37. University of Maryland, "Capacity Results for Multiple Antenna Multi-User Systems", College Park, MD, December 2004.
38. Army Research Laboratory, "Multi-user MIMO & Sensor Networks", Adelphi, MD, December 2004.

### **Funded Research Projects**

1. "CAREER: Exploring the Design and Fundamental Limits of Wireless Spatial Networks", PI, National Science Foundation (CAREER program), Feb. 2008 - Jan 2013.
2. "Rethinking Mobile Ad Hoc Networks: A Non-Equilibrium Information Theory", co-PI, Defense Advanced Research Projects Agency (Information Processing Technology Office), Oct. 2006 - May 2011.
3. "Collaborative Research: Cognitive Ad Hoc Networks: Capacity Optimization Through Local Adaptation", co-PI, National Science Foundation (CISE - Computing & Communications Foundations - Theoretical Foundations Cluster), Sept. 2006 - Aug. 2009.
4. "Integrated Scheduling and Broadband SDMA", PI, Motorola Corporation (University Partnership in Research), Sept. 2006 - May 2009.
5. "Wireless Technologies and Embedded Networked Sensing: Application to Integrated Urban Water Quality Management", co-PI, National Science Foundation (Geosciences - Earth Sciences - Hydrologic Sciences Program), Sept. 2006 - Aug 2008.
6. "IGERT: Non-Equilibrium Dynamics Across Space and Time: A Common Approach for Engineers, Earth Scientists, and Ecologists", senior personnel, National Science Foundation, CISE, Aug. 2005 - July 2010.
7. "Multiple Antenna Downlink Channels with Imperfect Transmitter Channel Knowledge", PI, Grant-in-Aid of Research, Artistry, and Scholarship, University of Minnesota Graduate School, Jan. 2005 - June 2006.